Current efforts on developing a HWIL synthetic environment for LADAR sensor testing at AMRDEC

Hajin J. Kim[*a], Michael C. Cornell[b], Charles B. Naumann[b]

[a]U.S. Army Aviation & Missile Command, Aviation & Missile RDEC, AMSAM-RD-SS-HW Bldg. 5400, Redstone Arsenal, AL 35898-5000

[b]Optical Sciences Corporation, P.O. Box 8291, Huntsville, AL 35808

ABSTRACT

Efforts in developing a synthetic environment for testing LADAR sensors in a hardware-in-the-loop simulation are continuing at the Aviation and Missile Research, Engineering, and Development Center (AMRDEC) of the U.S. Army Research, Engineering and Development Command (RDECOM). Current activities have concentrated on developing the optical projection hardware portion of the synthetic environment. These activities range from system level design down to component level testing. Of particular interest have been schemes for generating the optical signals representing the individual pixels of the projection. Several approaches have been investigated and tested with emphasis on operating wavelength, intensity dynamic range and uniformity, and flexibility in pixel waveform generation. This paper will discuss some of the results from these current efforts at RDECOM's Advanced Simulation Center (ASC).

Keywords: Hardware-in-the-loop, LADAR, seeker, simulation, projection

1. INTRODUCTION

AMRDEC continues with its efforts to create a synthetic environment for hardware-in-the-loop testing (HWIL) of LADAR seekers.[1, 2] To achieve this goal, development of a prototype LADAR simulator is underway. A LADAR simulator consists primarily of a LADAR scene generation computer and a LADAR scene projector (LRSP). The LADAR scene generation computer is responsible for running the LADAR model and generating frames of LADAR scenes based on its interaction with the other parts of the HWIL simulation environment. The LRSP takes this scene data and produces a temporally, radiometrically, and angularly correct optical projection that is directed into the receiver of the LADAR seeker under test.

Present efforts at AMRDEC have concentrated on developing prototype optical projection hardware, which would fill the LRSP role in the LADAR simulator. Two versions of a LRSP are currently under development. The system architecture and basic function of each LRSP is essentially the same. However, they differ in how they are being implemented to meet the projection requirements set for each. In this paper, the two systems (i.e., System A and System B) will be discussed along with being compared and contrasted to each other.

2. PROJECTOR SYSTEM ARCHITECTURE

The current focus of the AMRDEC efforts is addressing the testing requirements of an imaging LADAR seeker that operates in the direction detection mode (i.e., it collects range and intensity images of the target). In particular, the LADAR employs a scanning linear detector array in its receiver and its laser transmitter operated at 1064nm.

Consequently, the basic projector system architecture was developed from the functionality required to test a direct detection type of LADAR. This functionality can be broken down into three main parts. The first part is temporal characterization, which encodes the temporal characteristics (e.g., range) on to each pixel of the projection based on the temporal scene data received from the scene generation computer. The second part is optical signal generation, which

[*] hajin.j.kim@us.army.mil; phone: (256) 876-5088 x347

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**
4. TITLE AND SUBTITLE **Current efforts on developing a HWIL synthetic environment for LADAR Sensor testing at AMRDEC**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Optical Sciences Corporation,PO Box 8291,Huntsville,AL,35808**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

produces each pixel of the projection by combining the output from the temporal characteristics part with the optical intensity portion of the scene data from the scene generation computer. The final part is optical coupling, which is the optics required to deliver the projection pixels to the unit under test.

Figure 1 shows a block diagram of the system architecture based on functionality. Included in the diagram is an external trigger signal connected to the Temporal Characterization block. This trigger signal is required to cause the generation of the simulated LADAR return signals. Furthermore, this trigger signal must be related to the triggering of the LADAR transmitter if the range data contained in the projection is to be correct. This diagram of the system architecture served as the basis for developing the two projector systems discussed in this paper.

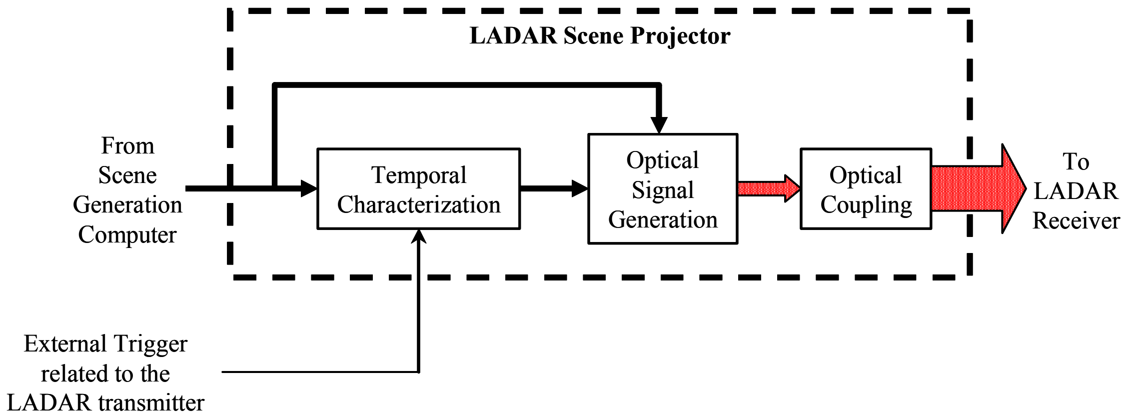

Figure 1. Projector system architecture block diagram

3. THE PROJECTORS

The two projector systems discussed in this section represent evolutionary steps in developing projectors for testing a scanning LADAR sensor containing a linear detector array in its receiver. With the first system (System A), the focus was to develop a relatively inexpensive system capable of stimulating the LADAR sensor, but it was not required deal with the scanning motion of the LADAR. Therefore, the sensor's scanning motion would be disabled (or removed from consideration) in order to employ System A for testing. The second system (System B) takes the projection effort to the next level. Its focus is to develop a projection scheme and system that can stimulate the scanning LADAR sensor while it's totally in operation. This has required a significant change in system design over System A.

Finally, the two projector systems are at different points in their development. System A is further along in development. A sub-set of this projector has been employed to test a LADAR receiver (See Ref.2) and it is anticipated that the whole system will be used for testing later in the year. System B is in the early stage of its development. Some components have been obtained and the characterization of them has begun. Other components are near the end of their design phase and fabrication has begun or is about to begin.

3.1 System A

System A was the initial optical projector to be developed at AMRDEC. It's a relatively simple system primarily intended to stimulate a LADAR receiver through direct optical signal injection into the detectors of the receiver. The system can simulate the LADAR return signals as either single optical pulses or dual pulses, which can represent first and last returns if desired.

The system consists of a set of VME based electronics primarily composed of commercial programmable digital delay generator (DDG) boards and custom built optical signal generator boards. Further details on these components can be found in Reference 2. The DDGs handle the temporal characterization (i.e., range and pulse width) of the simulated LADAR return based on the data provided over the VME bus. Their output is feed into the optical signal generators, which combines this input with amplitude (optical intensity) data provided over the VME bus to produce the pixels

(optical pulse(s)) of the simulated LADAR return. Each optical signal generator board contains two optical channels, which employ fiber coupled laser diodes as the optical sources for pixel generation. Therefore, the optical output from the optical channels is accessed through fiber optic cables, which is the optical coupling scheme employed when the projector is used for direct signal injection.

Figure 2 shows the system when it is configured to simulate the LADAR return signal with single optical pulses. For the system to generate dual pulses an additional set of four DDG boards are required. During testing of the projector hardware, a pulse generator serves as the external trigger source and a PC computer serves as a scene generation computer to supply data to the system via the VME bus.

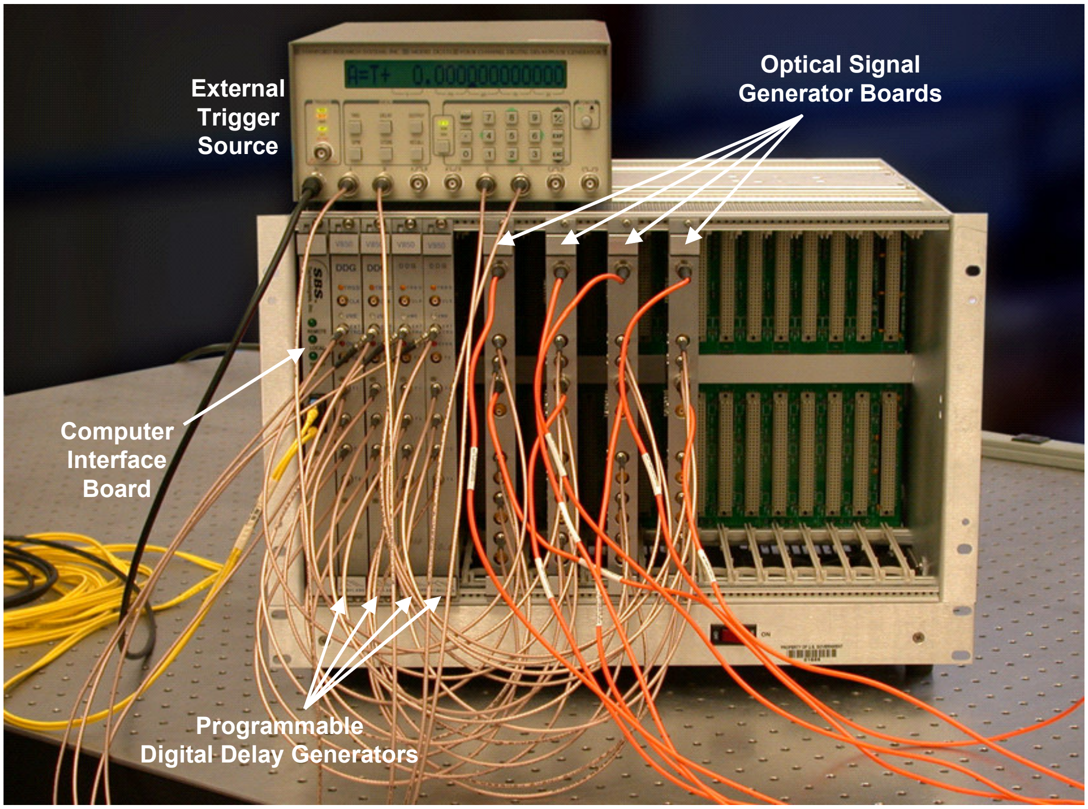

Figure 2. System A projector configured to simulate a single pulse return

The operational performance of System A is summarized in Table 1. There are several things to note in these performance specifications. The first is the minimum range that the system can simulate. This value can be effectively 0 if an optical channel from the projector is used to simulate the pick-off signal from when the LADAR transmitter would fire. Otherwise, the minimum range is defined by the trigger signal insertion delay, which is primarily the time it takes the external trigger signal to propagate through the system electronics and produce an optical signal.

The second item is the operating wavelength of the optical channels (i.e., the laser diode sources). It is nominally in the range of 1064nm, which is not a significant factor when performing direct signal injection unless a narrowband laser line filter would be employed in the receiver hardware.

The final item is the dynamic range of the optical intensity for the system. Figure 3 shows the typical performance of the optical channels over the complete range of applied operating currents to the laser diode sources. The amplitude of the current applied to each laser is controlled by a 16-bit DAC. Optical radiation can be sensed over about six orders. However, over about half of this range, the laser sources are operating under the lasing threshold and are essentially behaving like LEDs. Operation in the LED (or spontaneous emission) region is unlikely to be useable to test LADAR

receivers due to degradation in the desired temporal characteristics (e.g., slower risetime, pulse width broadening, jitter) and the energy output is over a significantly broad band of wavelengths compared to a laser. Therefore, the lasing region is the only part of these performance curves that should be used to determine the effective optical intensity dynamic range for the system.

Table 1. Operational performance of System A

Range Simulation Modes:	Single-Pulse, Dual-Pulse
Number of Optical Channels:	8
Time Delay (Range)	
Resolution:	0.5ns (0.075m)
Maximum:	>>33.3μs (>>5000m)
Minimum:	~0ns (~0m) if simulating transmitter pick off signal Otherwise, <100ns (15m) due to trigger signal insertion delay
Pulse Width	
Resolution:	<0.5ns
Maximum:	Equivalent to Maximum Delay
Minimum:	4ns
Modulation Rate:	>20kHz (Max)
Operating Wavelength:	1065±10nm
Optical Intensity	
Maximum Peak Power:	~10mW
Dynamic Range:	~20dB
Control Range:	~8-bits

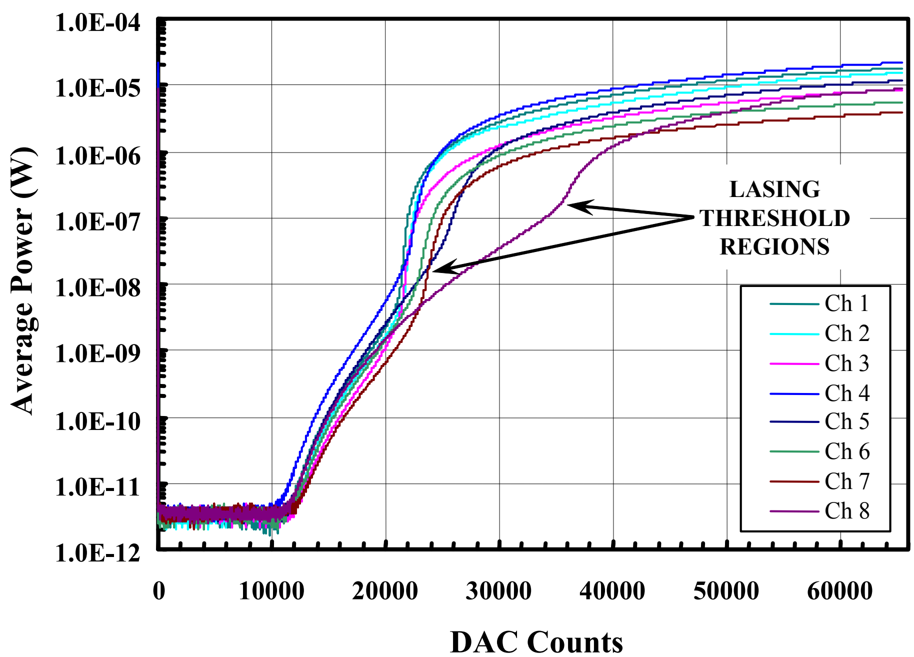

Figure 3. Average output power from the optical channels of System A for 10ns pulse at 100kHz rep rate

Figure 4 is a closer view of the lasing region. To establish the dynamic range, it is bounded at the top by the channel with the lowest output power and at the bottom by the lasing threshold of the channel which occurs at the highest power point. Channel 7 defines the up bound and Channel 8 would define the lower bound except for the fact only seven channels are required to stimulate the receiver based on the stated design rules. Therefore, Channel 8 can be reserved to

always represent the pick-off of the LADAR transmitter firing. The lower bound is defined by the performance of Channel 5, which has the lasing threshold at the next highest power point. Consequently, the dynamic range for the projector system is around 20dB.

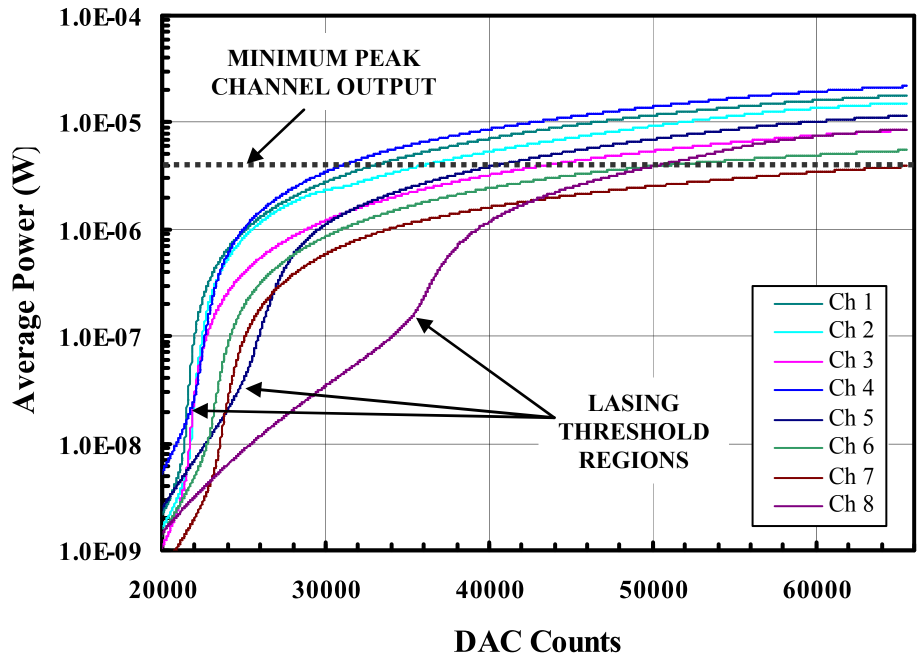

Figure 4. A closer view of only the lasing region

Finally, System A has served as the principal tool for exploring the nuances in employing a LADAR scene projector in a HWIL simulation environment. The lessons learned from operating this projector have influenced the future development of LADAR scene projectors at AMRDEC.

3.2 System B

System B is in the middle of its development. It is a more ambitious endeavor compared to System A. The goal of System B is to be able to project the simulated LADAR return signals directly into the LADAR sensor while it is performing its normal scanning motion. This is a formidable task.

3.2.1 Addressing the scanning motion

The scanning motion of the seeker is a superposition of two different scanning motions. The first is a relatively high frequency scan (NOD) motion in roughly the vertical direction, which is effectively a scan of the linear detector array oriented horizontally with respect to the scan direction. The second is a low frequency (~few Hz) scan, which results in the NOD scan being moved in roughly the horizontal direction. Through the combination of these two motions, the LADAR image (or scene frame) is formed. Consequently, it would be practically impossible for the projector to match (synchronize with) the scanning motion of the sensor. Therefore, an alternate approach to address the scanning motion had to be determined.

The AMRDEC approach to addressing the scan motion will be to use the Flight Motion Simulator to which the LADAR sensor is attached to neutralize (or minimize) the effects of the slower horizontal scan motion of the seeker. This would effectively keep the NOD scan stationary in front of the projector.

To deal with the NOD scan, the approach is to shape the output from each optical channel of the projector into a set of vertical line projections. The vertical extent of the line projections would cover the angular extent of the NOD scan. Rather than attempting a perfect one-to-one projection of vertical line to detector, the objective is project four vertical

lines within the angular separation of the detectors so that each detector would see the output from at least three line projections as it is scanned. Figure 5 illustrates this approach. The optical radiation collected by a detector at any instance would represent the projected pixel. This approach should allow the test setup to deal with misalignment of the projection with LADAR sensor along with the uncertainties in the seeker motion. Consequently, the projector requires at a minimum four times the number of optical channels as detectors in the receiver array. In practice, additional optical channels would be required to handle misalignment in the horizontal direction of the sensor's field of view.

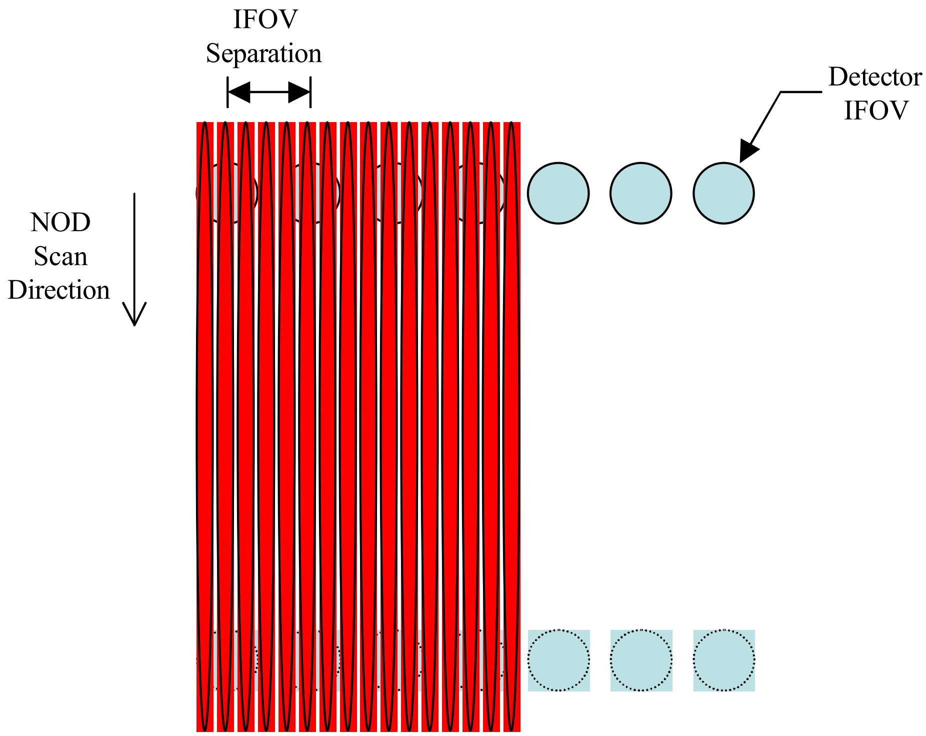

Figure 5. Projection concept to deal with the NOD motion

3.2.2 Additional design goals

Along with handling the scanning motion of the LADAR sensor, System B must meet some minimum operational goals for it to be effective. Table 2 lists some of the additional operational goals that the projector must meet. In general, these performance goals are similar to the capabilities stated for System A. However, there are a number of differences.

Table 2. System B operational goals

Wavelength:	1064nm±1nm
Number of Optical Channels:	48
Range:	15m to >5000m
Range Resolution:	<0.15m
Minimum Pulse width:	~10ns
Pixel Generation Rate per Optical Channel:	>20kHz
Number of sub-returns per pixel:	Initially 1 Future: TBD
Maximum Pixel Peak Power:	>30µW
Intensity Dynamic Range:	>40dB

The wavelength requirement on System B is more stringent than how System A operates. With System B projecting through the optical aperture of the LADAR it must deal with any filtering, which would be installed in front of the detectors in order to minimize the background radiation sensed by the detectors. Typically, only the radiation at the transmitter's wavelength is allowed to pass.

The number of optical channels resulted from the stated concept for handling the LADAR scan motion. A minimum of 28 channels is required just to cover the extent of the NOD scan. To deal with misalignment, a conservatively chosen additional ten channels would be added to either side of the core 28 channels. Thus, the total number of optical channels for the projector is 48.

Finally, the intensity dynamic range for System A was only around 20dB, which is inadequate for simulating the total change in intensity due to simple range closure on the target. Therefore, a greater dynamic range is required out of System B and based on a simple range closure model of the intensity the minimum requirement is at least 40dB.

3.2.3 Current status

Due to the risk involved with the projection scheme to be employed, it was decided that a sub-set of the projector consisting of 16 optical channels would be developed at this time. This size system should be adequate to determine if the approach is viable.

The current development has been focused in two areas, optical signal generation and optical coupling. Initially, the temporal characterization portion of the projector will be handled in the same manner as in System A, i.e., through the use of commercial programmable digital delay generators. Eventually, custom electronics will be developed to facilitate the generation of a more complex optical waveform other than a simple square pulse to simulate the LADAR return signal.

3.2.3.1 Optical signal generation

With System B, the use of modulated laser diode output to generate the simulated LADAR return signals was rejected due to the poor intensity dynamic range performance of this approach shown in System A. The choice in this instance is to employ a CW Fiber laser operating at 1064nm and fusion splice its output to a 1x16 optical fiber splitter to provide 16 channels of nearly identical CW output. Each output would be connected to a fiber-coupled acousto-optic (AO) modulator, which is responsible for generating the simulated LADAR return signal from the RF waveform input to the modulator. The output from each modulator would be feed into a linear optical fiber array, which would facilitate designing the optical coupling scheme described in Section 3.2.1.

There were several reasons for choosing this approach. One reason for this choice is that the modulators easily lend themselves to generating complex optical waveforms, which may be desired for simulating the LADAR return signals. Another more important reason is that both types (integrated optic and AO) of commercially available fiber-coupled intensity modulator offered an intensity dynamic range of at least 40dB. The primary reason the AO modulator was chosen over the Lithium Niobate based integrated optic modulator was the limitation on CW laser power that could be introduced into the modulator. The integrated optic modulators were limited to 100mW to prevent damaging the Lithium Niobate structure. The upper limit on the AO modulators was 2W. Given the proposed optical coupling scheme, it would be prudent to maximize the amount of optical energy that could be put into the projection.

One caveat with using an external intensity modulator on a CW input is that no modulator can perfectly extinguish the CW input. Consequently, there is always a low level CW throughput even when the modulation is off. Whether this may be an issue with testing the LADAR has yet to be determined.

Presently, some of the optical signal generation hardware has arrived in the lab and preliminary testing of the components has begun. Figure 6 shows the Fiber laser/1x16 splitter unit that has been purchased. At the fiber laser's maximum operating current setting, each port of the splitter has an output between 170 and 180mW. Only a single fiber-coupled AO modulator along with its RF driver unit is currently available and little testing of the modulator has been done yet.

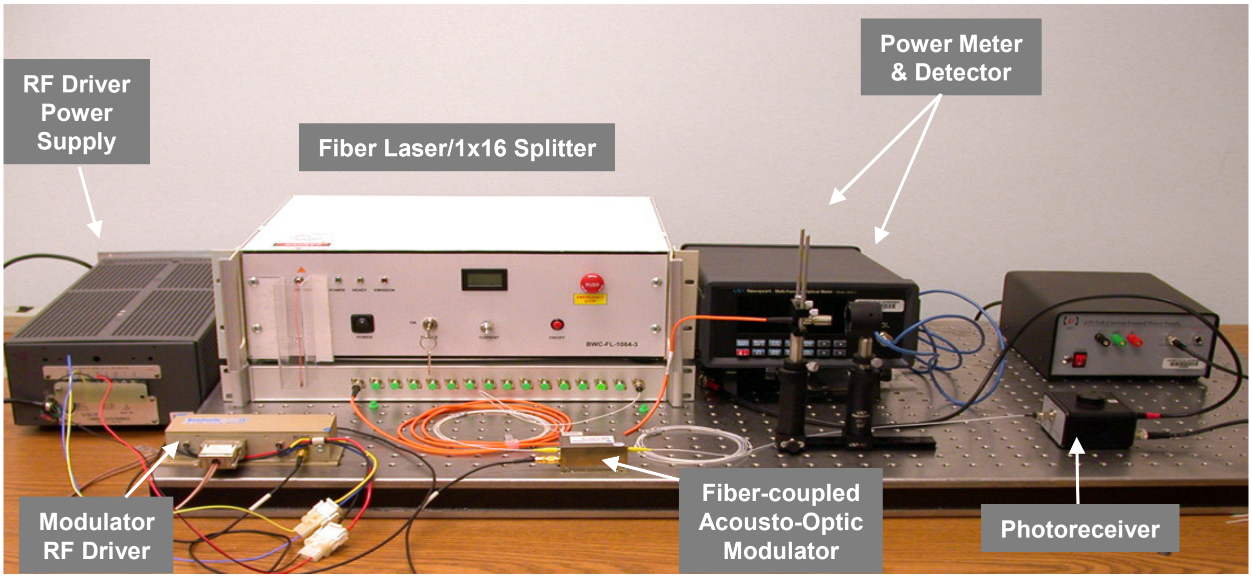

Figure 6. Test setup for evaluating the performance of the Fiber Laser/Splitter unit and the acousto-optic modulator

3.2.3.2 Optical coupling

The design of the optical coupling is near completion. It has been an extremely difficult process. The design goal has been to image a 16x1 array of optical fiber ends at infinite conjugate. The resulting image should cover an angular extent of 1.6x69.8mrad. The size of the image dimensions makes a traditional anamorphic collimating system impractical. As an alternative, a combination of light diffuser and lenslet array is employed to expand the sources asymmetrically. This reduces the ratio of the focal lengths to a more manageable 15:1. Figure 7 shows a diagram of the optical design.

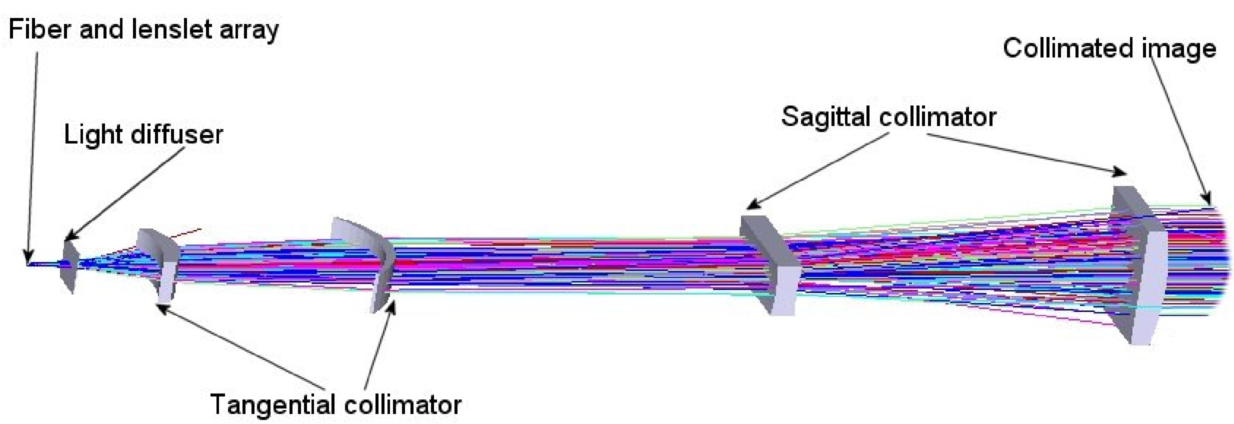

Figure 7. CAD drawing of the optical coupling design

The function of the lenslet array is to expand the sources in the tangential axis (axis perpendicular to the fiber array). As the radiation expands in this axis it remains collimated in the sagittal plane. These elliptically shaped sources are then incident upon a light diffuser that serves as an intermediate image for collimation.

There is still some refinement in the design to occur. However, vendors have been identified to manufacture the components identified in Figure 7 as soon as the design can be finalized.

4. CONCLUSION

Recent efforts at AMRDEC in LADAR scene projection development have been reported. Two systems at different points in their development have been described and compared. This discussion has provided insight into what development of optical projection for testing LADAR sensors in a HWIL simulation environment entails.

ACKNOWLEDGEMENTS

The authors wish to thank Matt Bender of Optical Sciences Corporation for his efforts on the design of the optical coupling scheme for System B and providing us with the CAD image of the optical layout.

REFERENCES

1. H.J. Kim, S.B. Mobley, and J.A. Buford, “AMCOM RDEC LADAR HWIL Simulation System Development,” in *Proceedings of SPIE* Vol. **5092**, Technologies for Synthetic Environment: Hardware-in-the-Loop Testing VIII, R.L. Murrer, Jr., Ed., pp. 288-294, 2003.

2. H.J. Kim, M.C. Cornell, and C.B. Naumann, “AMRDEC’s HWIL Synthetic Environment Development Efforts for LADAR sensors,” in *Proceedings of SPIE* Vol. **5408**, Technologies for Synthetic Environment: Hardware-in-the-Loop Testing IX, R.L. Murrer, Jr., Ed., pp. 203-214, 2004.